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MINERALOGICAL AND IMAGE ANALYSIS STUDY OF THREE TI-BEARING SAMPLES FROM QUEBEC IRON AND TITANIUM COMPANY INCORPORATED

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MINERALOGICAL AND IMAGE ANALYSIS STUDY OF THREE TI-BEARING SAMPLES FROM QUEBEC IRON AND TITANIUM COMPANY INCORPORATED

by

William Petruk

ABSTRACT

A mineralogical and image analysis study of three samples from Quebec Iron and Titanium Company Incorporated was done to determine whether the titanium occurs in a recoverable form. Two samples are tailings that contain about 6.5 wt % TiO_2, and one is a fine grained product (Sumerse 30") that contains more than 20 wt % TiO_2. Most of the titanium occurs as ilmenite, but a small proportion is in rutile, and a trace proportion is in silicate minerals. The ilmenite occurs in ilmenite-hematite grains that contain an average of 20 vol % hematite as lamellae. The ilmenite-hematite grains are largely free; more than 85 vol % are in particles that contain more than 70 vol % ilmenite-hematite and less than 30 vol % silicate minerals. The average amount of silicate minerals attached to the ilmenite-hematite grains is less than 8 vol %. The size of the ilmenite grains in the two tailing samples varies from about 26 to 208 μm in diameter, whereas in Sample Sumerse 30" the grain size varies from about 6 to 52 μm.

Keywords: Titanium, ilmenite, rutile, hematite, Quebec Iron and Titanium Co.

INTRODUCTION

A mineralogical and image analysis study was carried out on three samples from Quebec Iron and Titanium Company Incorporated (QIT) as a cost recovery project No. 025512 for Mr. P. Fallon of QIT. Mr. Fallon stated that the samples represented tailings from various processes and requested that they be analyzed to determine whether the titanium occurs in a recoverable form.

SAMPLES

Three samples of crushed material, and their chemical analyses were supplied (Table 1). The samples were labelled C-127, C-157 and Sumerse 30".

Table 1. Chemical analyses* of samples

Oxide	C-127	C-157	Sumerse 30"
TiO_2	6.0	6.6	23.7
Fe (total)	8.55	12.05	29.0
Al_2O_3	23.2	30.35	8.5
CaO	6.8	3.8	3.0
MgO	4.0	9.0	4.5
P_2O_5	0.15	0.18	0.19
MnO	0.04	0.07	0.12
SiO_2	43.9	27.4	14.0
Cr_2O_3	0.04	0.27	0.11
V_2O_5	nil	nil	0.04
ZrO_2	0.09	0.3	0.43

* analyses supplied by Mr. Fallon

METHOD OF INVESTIGATION

Samples C-127 and C-157 were screened into plus 208 μm (+65 mesh) and minus 208 μm (-65 mesh) fractions because the particles have a wide size range. Polished sections were prepared from the screened fractions and from sample Sumerse 30". The minerals observed in the polished sections were identified with the energy dispersive X-ray analyzer (EDXA), and mineral quantities, size distributions of the particles, and mode of occurrence of the titanium-bearing minerals were determined with the image analysis system. Data obtained for the screened fractions of samples C-127 and C-157 were combined for the respective samples by using the weight per cent of each fraction.

MINERALOGY

The silicate minerals identified in the samples are feldspar, mica (phlogopite-biotite series), Ca-pyroxene, Fe-pyroxene, amphibole, titanite, zircon and quartz; the carbonate mineral is calcite; the phosphate mineral is apatite; the oxide minerals are ilmenite, rutile, iron oxides (hematite and/or magnetite), Mg-spinel and corundum; the sulphide is pyrite, and the metal mineral is iron. Mineral quantities in each fraction were determined with the image analyzer and the data were combined into mineral quantities for each sample (Table 2). The Al_2O_3, MgO, CaO, P_2O_5, SiO_2, ZrO_2 are accounted for by the silicate, carbonate and phosphate minerals, and by the Mg-spinel. Most of the iron in the samples is present as iron oxides (mainly hematite) and ilmenite, but some is present as Fe-bearing silicates and iron metal. In particular, a significant portion of the iron in sample C-157 occurs as an iron-rich mica. Most of the TiO_2 occurs in ilmenite, but a small proportion is in rutile, and a trace proportion is in mica, amphibole and titanite.

SIZE DISTRIBUTIONS

The size distributions of the particles in the samples are given in Table 3 and shown graphically in Figure 1. The results show that all particles in Sample Sumerse 30" are smaller than 74 μm (200 mesh), and 84.8 and 89.5 vol % of the particles in samples C-127 and C-157 respectively are larger than

208 μm (65 mesh). By contrast, the screen analyses gave 76.3 and 78.3 wt % of particles larger than 208 μm for Samples C-127 and C-157 respectively. The difference is due to a variety of factors; (1) wt % versus vol %, (2) analyzing polished sections vs screening, and (3) using equivalent circular diameter (Dcircle) as size of particle rather than equivalent square diameter (DIA(MIC)) during image analysis measurements. The particle size analysis based on (DIA(MIC)) corresponds better to screen analysis than particle size analysis based on (Dcircle).

MODE OF OCCURRENCE OF TiO_2

Most of the TiO_2 is present in the mineral ilmenite, but some is in rutile, and a trace amount is in phlogopite, amphibole and titanite. The ilmenite generally occurs in grains that contain hematite lamellae, and some is partly altered to rutile. Some of the ilmenite-hematite grains are attached to grains of silicate minerals, but many appear free or nearly free in polished sections. Small amounts of the ilmenite and rutile also are present as free grains. Two electron backscattered photographs are included in this report for each sample (Figs. 2A-2F). One photograph shows the relationship of the ilmenite-hematite grains to the silicate minerals, and the other shows the relationship of ilmenite to hematite.

LIBERATION CHARACTERISTICS OF ILMENITE

The liberation characteristics of the ilmenite-hematite grains with respect to silicate and other gangue minerals were determined with the image analyzer for the sized fractions of samples C-127 and C-157 and for sample Sumerse 30". Data for the sized fractions were combined into data (total) for each sample. Particles with ilmenite-hematite grains were classified as containing 0-10, 10-20, 20-30, 30-40, 40-50, 50-60, 60-70, 70-80, 80-90, 90-99.99 and 100 vol % ilmenite-hematite (rutile was included in the ilmenite-hematite grains). For purposes of this investigation particles containing more than 90 vol % ilmenite-hematite grains are considered as free ilmenite-hematite grains. Results of the analyses (combined data for samples C-127 and C-157 and data "as analyzed" for sample Sumerse 30") are shown in the top diagrams of Figures

3, 4 and 5, and in the sections of Tables 4, 5 and 6 which are designated as computer Table 3. A summary of the results (Table 7) shows that only a small proportion of the ilmenite-hematite is completely free of silicate materials (100 vol % class), but 67.4 %, 76.6 % and 55 % of the ilmenite-hematite grains in samples C-127, C-157 and Sumerse 30" respectively occur in particles that contain more than 90 vol % ilmenite-hematite grains (i.e. essentially free ilmenite-hematite grains). It is also significant that 92.3 vol %, 84.3 vol %, and 85.7 vol % of the ilmenite-hematite grains in Samples C-127, C-157 and Sumerse 30" respectively occur in particles that contain more than 70 vol % ilmenite-hematite grains. The overall vol % silicates in particles that contain more than 70 vol % ilmenite-hematite grains was calculated as 7.4, 5.4 and 8.3 in samples C127, C-157 and Sumerse 30" respectively. The sizes of the ilmenite-hematite grains are included in the middle and 3D diagrams in figures 3, 4 and 5, and in Tables 4, 5 and 6. The results show that most ilmenite-hematite grains in samples C-1.. and C-157 vary from 26 to 208 μm in diameter, but in sample Sumerse 30" they vary from 6 to 52 μm in diameter.

The overall amount of ilmenite in the ilmenite-hematite grains was determined with the image analyser by measuring the total surface areas of the ilmenite and of the hematite in the ilmenite-hematite grains. The results show that the ilmenite content in the ilmenite hematite grains varies from 68 vol % for sample sumerse 30" to 75 vol % for sample C-157 (Table 8).

The ilmenite-hematite grains were classified as containing 0-10, 10-20, 20-30, 30-40, 40-50, 50-60, 60-70, 70-80, 80-90, 90-99.99 and 100 vol % ilmenite + rutile (computer Table 4 in Tables 4, 5 and 6, and second row of diagrams in Figs 3, 4 and 5). The results show that 9.7 vol % of the ilmenite + rutile in sample Sumerse 30" and 60.6 vol % in sample C-157 are in ilmenite-hematite grains that contain more than 90 vol % ilmenite + rutile (Table 7). By contrast, 81.9 to 99.4 vol % of the ilmenite + rutile in samples Sumerse 30" and C-157 respectively is in ilmenite-hematite grains that contain more than 60 vol % ilmenite + rutile.

CONCLUSIONS

1. The TiO_2 in the samples occurs largely in ilmenite. A small proportion is in rutile, and trace proportions are in phlogopite, amphibole and titanite.

2 The ilmenite and some of the rutile occur in ilmenite-hematite grains that contain variable amounts of ilmenite. The average amount of ilmenite + rutile in these grains varies from 69 vol % in sample Sumerse 30", to 75 vol % in sample C-157. However, if only grains containing more than 60 vol % ilmenite + rutile are considered, the average amounts of ilmenite + rutile in the ilmenite-hematite grains would be 84 and 90 vol % for the respective samples. These plus 60 % ilmenite grains account for 82 vol % of the ilmenite + rutile in the sample Sumerse 30" and 99 vol % in sample C-157.

3. The ilmenite-hematite grains are largely free although small amounts of silicate minerals are attached to them. Particles containing more than 70 vol % ilmenite plus hematite account for 92.3% of the ilmenite-hematite grains in samples C-127, 84.3 % in C-157 and 85.7 Sumerse 30". The average amounts of silicate minerals in these particles is 7.4, 5.4 and 8.3 vol % in sample C-127, C-157 and Sumerse 30" respectively.

4. It should be possible not only to recover TiO_2 from material represented by the three samples, but also to obtain high recoveries. The concentration method for recovering the TiO_2 from samples C-127 and C-157 must be applicable to concentrating ilmenite-hematite grains that range from 26 to 208 μm in diameter; for sample Sumerse 30", however, the concentration method must be applicable to ilmenite-hematite grains that vary from 6-52 μm in diameter.

5. It is interpeted that the best concentrates that can be produced without regrinding would contain about 15 to 20 wt % hematite and about 5-7 vol % silicate minerals. These concentrates, therefore, would contain about 75 wt % ilmenite, or about 40 wt % TiO_2. The maximum possible recoveries of

TiO_2 in such concentrates would be about 90 % for samples C-127 and C-157, and 80 % for sample Sumerse 30".

Table 2. Quantities of minerals in samples.

Minerals	C-127			C-157		Sumerse	
	+208 μm wt%	-208 μm wt%	Total wt%	+208 μm wt%	-208 μm wt%	Total wt%	30" wt%
Feldspar	71.1	42.7	64.4	40.8	33.7	39.2	20.5
Mica, Mg-spinel calcite	9.3	7.2	8.8	38.4	32.6	37.1	7.7
Pyroxine, amphibole titanite	3.2	3.5	3.3	5.8	5.5	5.7	1.1
Quartz, corundum	0.1	0.3	0.1	2.3	2.5	2.3	0.1
Apatite	0.6	0.6	0.6	1.0	1.7	1.2	tr.
Iron oxides (hematite, magnetite)	5.7	19.7	7.9	3.2	3.6	3.3	19.8
Ilmenite	9.3	29.5	14.0	7.4	18.4	9.8	34.9
Rutile	0.6	0.8	0.7	1.1	1.2	1.2	1.5
Zircon + pyrite	0.1	0.7	0.2	tr	0.8	0.2	5.7
Iron	-	-	-	-	-	-	8.7
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0
wt % of fraction	76.3	23.7	100.0	78.3	21.7	100.0	100.0
Calc. TiO_2			8.1			6.4	19.9
Anal. TiO_2 (from Table 1)			6.0			6.6	23.7

Table 3. Size distributions* of particles in samples

Size Mm	C-127	C-157	Sumerse 30"
-3.25	-	-	3.4
-4.6	-	-	6.0
-6.5	-	-	9.5
-9.2	0.02	-	15.1
-13.0	0.04	0.02	23.2
-18.4	0.1	0.04	37.2
-26.0	0.3	0.1	55.1
-37.0	0.6	0.2	77.5
-52.0	1.1	0.5	93.2
-74.0	2.2	1.1	100.0
-104.0	4.4	2.6	100.0
-147.0	8.2	5.1	100.0
-208	15.6	10.5	100.0
+208	84.4	89.5	0.0

Table 4. Data for classifications and size distributions: (a) ilmenite-hematite grains in ilmenite-hematite-silicate particles (computer table 3) (b) ilmenite in ilmenite-hematite grains (computer table 4). The data were used to plot the histograms and 3 diagrams of Fig. 5. For computer table 3 the top line defines the classes of the particles. The bottom line is a summary classification of the particles, and the right column is a summary size distribution of the grains in the particles.

DEF 834 C-127 COMBINED 512*512

table 0 3 SUMS
variable z: PER CENT
variable x: PHASES
variable y: DIA(MIC)

	9.99	20.0	30.0	40.0	50.0	60.0	70.0	80.0	90.0	100.0	
	.507E-02	0.00	.906E-04	0.00	0.00	.272E-03	.997E-03	.202E-02	.103E-02	.574E-03	.105E-01	.206E-01
3.25	.184E-01	.483E-03	.213E-02	0.00	.544E-03	.332E-03	.124E-02	.164E-02	.332E-02	.169E-02	.125E-01	.423E-01
4.60	.296E-01	.731E-02	.495E-02	.385E-02	0.00	0.00	.118E-02	.294E-02	.462E-02	.994E-02	.443E-01	.107
6.50	.394E-01	.113E-01	.371E-02	.489E-02	.444E-02	.365E-02	.851E-02	.538E-02	.495E-02	.795E-01	.937E-01	.253
9.19	.528E-01	.194E-01	.141E-01	.108E-01	.208E-01	.133E-01	.140E-01	.128E-01	.613E-01	.284	.310	.812
13.0	.137	.579E-01	0.00	.622E-02	.168E-01	.352E-01	.514E-01	.726E-01	.110	.982	.594	2.06
18.4	.187	.687E-01	.123	.578E-01	.328E-01	.128E-01	.692E-01	.152	.382	3.22	.815	5.05
26.0	0.00	0.00	.231	0.00	.736E-01	.232	.722E-01	.363	1.11	10.1	1.02	13.2
36.8	0.00	0.00	0.00	.429E-01	.719E-01	.300	.436	.665	.959	15.7	.639	18.8
52.0	0.00	.253	0.00	0.00	.319	0.00	0.00	.123	.615	9.87	0.00	11.2
73.5	0.00	0.00	0.00	0.00	.728	.628	.947	.663	.512	5.42	0.00	8.92
104.	0.00	0.00	0.00	0.00	1.05	1.18	0.00	0.00	2.34	7.41	0.00	12.0
147.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.31	2.17	5.24	0.00	9.73
208.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	12.2	5.65	0.00	17.9
	.486	.411	.279	.125	0.33	2.41	1.60	4.37	20.5	63.9	3.54	100.

table 0 4 SUMS
variable z: PER CENT
variable x: PHASES
variable y: DIA(MIC)

	9.99	20.0	30.0	40.0	50.0	60.0	70.0	80.0	90.0	100.0		
	.254E-02	.232E-02	.122E-02	.293E-03	.813E-03	.184E-02	.264E-02	.319E-02	.251E-02	.796E-03	.131E-01	.312E-01
3.25	.112E-01	.352E-02	.393E-02	.277E-02	.373E-02	.117E-01	.130E-01	.141E-01	.102E-01	.732E-02	.366E-01	.118
4.60	.187E-01	.142E-01	.444E-02	.918E-02	.754E-02	.859E-02	.276E-01	.371E-01	.448E-01	.326E-01	.427E-01	.239
6.50	.188E-01	.448E-01	.334E-01	.213E-01	.155E-01	.199E-01	.337E-01	.753E-01	.118	.568E-01	.759E-01	.513
9.19	.582E-02	.969E-01	.604E-01	.393E-01	.927E-01	.569E-01	.648E-01	.148	.359	.168	.689E-01	1.15
13.0	0.00	.656E-01	.129	.296	.291	.145	.274	.336	.843	.549	.852E-01	2.92
18.4	0.00	.337E-01	.271	.411	.686	.819	.691	.778	2.45	1.56	.513E-01	7.67
26.0	0.00	0.00	.144	.118	.852	1.13	1.46	2.17	5.18	3.58	.247	14.7
36.8	0.00	0.00	0.00	.188	.286	.988	1.94	2.78	6.85	4.69	0.00	17.8
52.0	0.00	0.00	0.00	0.00	0.00	.588	1.48	1.98	3.72	2.55	0.00	10.3
73.5	0.00	0.00	0.00	0.00	0.00	0.00	.752	6.02	1.95	.948	0.00	8.75
104.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.98	9.02	3.19	0.00	16.2
147.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.03	0.00	0.00	0.00	3.03
208.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	17.4	0.00	0.00	0.00	17.4
	.484E-01	.261	.647	.903	2.15	3.76	6.73	38.7	29.0	17.2	.629	100.0

DEF 834 C-127 COMBINED 512*512

Table 5. Data for classifications and size distributions: (a) ilmenite-hematite grains in ilmenite-hematite-silicate particles (computer table 3); (b) ilmenite in ilmenite-hematite grains (computer table 4). The data were used to plot the histograms and 3 diagrams of Fig. 6. For computer table 3 the top line defines the classes of the particles. The bottom line is a summary classification of the particles, and the right column is a summary size distribution of the grains in the particles.

table 0 3 SUMS
variable z: PER CENT
variable x: PHASES
variable y: DIA(MIC)

9.99	20.0	30.0	40.0	50.0	60.0	70.0	80.0	90.0	100.0		
.117E-01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	.675E-02	.185E-01
3.25											
.559E-01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	.106E-01	.666E-01
4.68											
.841E-01	0.00	0.00	0.00	.435E-02	.626E-02	.553E-03	.553E-03	.699E-02	0.00	.101E-01	.113
6.50											
.121	.967E-02	0.00	0.00	0.00	0.00	.783E-03	.452E-03	.186E-02	.145E-01	.965E-02	.158
9.19											
.182	.276E-02	.131E-02	.231E-02	.126E-02	.111E-02	.144E-02	.492E-02	.322E-02	.486E-01	.672E-02	.252
13.0											
.839	.577E-01	.156	.176E-02	.211E-02	.327E-02	.517E-02	.789E-02	.151E-01	.898E-01	.343E-01	1.21
18.4											
1.15	.186	.124E-01	.179E-01	.548E-02	.184	.347E-02	.291E-01	.228E-01	.293	.126	1.87
26.0											
.863	.232	.209	.195E-01	.214	0.00	.384E-01	.392E-01	.469	2.95	.263	4.49
36.8											
.788E-01	.815	.689	0.00	.853	.379	.459	.496E-01	.830	4.42	.211	8.78
52.0											
.383E-01	1.39	1.83	.707	.650	.975E-01	2.00	.577	3.87	15.2	.784E-01	24.9
73.5											
0.00	.148	.883E-01	2.03	.173	1.32	1.48	0.00	3.25	17.3	.788E-01	25.7
104.											
0.00	0.00	0.00	0.00	.282	.168	.411	.348	2.72	14.1	.195	18.2
147.											
0.00	0.00	0.00	.242	0.00	0.00	0.00	.233	0.00	13.7	0.00	14.2
208.											
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3.48	2.75	2.84	3.00	2.18	2.00	4.40	1.30	18.4	67.2	1.03	100.

table 0 4 SUMS
variable z: PER CENT
variable x: PHASES
variable y: D-HOST

9.99	20.0	30.0	40.0	50.0	60.0	70.0	80.0	90.0	100.0		
0.00	.384E-03	0.00	.384E-03	.767E-03	.767E-03	.483E-02	.537E-02	.767E-02	.173E-02	.683E-01	.894E-01
3.25											
0.00	0.00	0.00	0.00	0.00	.115E-02	.345E-02	.767E-02	.292E-01	.224E-01	.175	.239
4.68											
0.00	0.00	.150E-03	.247E-02	.250E-02	.112E-01	.183E-01	.168E-01	.549E-01	.584E-01	.250	.406
6.50											
.183E-03	.516E-04	0.00	.569E-02	.384E-02	.693E-02	.192E-01	.227E-01	.463E-01	.927E-01	.426	.624
9.19											
.155E-03	0.00	.361E-03	.464E-03	.122E-01	.230E-02	.371E-01	.428E-02	.187	.111	.588	.863
13.0											
.843E-02	0.00	0.00	.722E-03	.843E-02	.368E-01	.388E-01	.119	.168	.542	.644	1.35
18.4											
.767E-03	.774E-03	.459E-02	.150E-02	0.00	.488E-02	.529E-01	.144E-01	.237	.722	.989	1.95
26.0											
0.00	.658E-02	.371E-02	.157E-01	.799E-02	.459E-02	.821E-01	.500E-01	1.86	1.97	1.33	4.47
36.8											
.240E-01	.818E-02	.918E-02	.918E-02	0.00	.182E-01	.373	.445	.774	6.38	2.55	10.5
52.0											
.654E-01	.743E-02	0.00	0.00	.312E-01	.418E-01	.787	2.62	4.11	12.1	2.49	22.3
73.5											
0.00	0.00	0.00	0.00	0.00	.549E-01	1.33	2.68	4.59	15.1	1.90	25.7
104.											
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.41	7.83	2.15	15.8
147.											
0.00	0.00	0.00	0.00	0.00	0.00	0.00	.436	5.47	2.39	0.00	8.30
208.											
0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.83	0.00	0.00	0.00	7.83
.991E-01	.232E-01	.168E-01	.362E-01	.611E-01	.181	2.67	14.3	22.1	47.1	13.5	100.0

Table 6. Data for classifications and size distributions: (a) ilmenite-hematite grains in ilmenite-hematite-silicate particles (computer table 3); (b) ilmenite in ilmenite-hematite grains (computer table 4). The data were used to plot the histograms and 3 diagrams of Fig. 7. For computer table 3 the top line defines the classes of the particles. The bottom line is a summary size distribution of the grains in the particles.

DEF 834 BUMERS 017 512*512

table # 3 BUMB
variable z: PER CENT
variable x: PHASES
variable y: DIA(MIC)

9.99	20.0	30.0	40.0	50.0	60.0	70.0	80.0	90.0	100.0		
.329	.259	.199	.126	.101	.939E-01	.119	.882E-01	.120	.299	.289	2.02
3.25											
.582E-01	.138	.111	.677E-01	.147	.196	.141	.220	.357	1.12	.391	2.94
4.68											
.298E-01	.219E-01	.105	.264	.101	.376	.483	.537	.778	2.41	.335	5.53
6.58											
.789E-01	.354E-01	.134	.295	.375	.468	.883	1.06	1.66	3.48	.982E-01	8.48
9.19											
0.00	.711E-01	.291	.165	.276	.635	1.03	1.42	3.98	7.58	.731E-01	15.4
13.8											
0.00	.167	.228	.151	.742	.488	1.19	1.55	6.05	12.8	0.00	22.7
18.4											
0.00	0.00	0.00	0.00	0.00	.318	.633	8.47	3.17	9.15	0.00	15.7
23.0											
0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.53	3.29	12.4	0.00	17.2
36.8											
0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.23	1.25	5.24	0.00	7.72
52.0											
0.00	0.00	0.00	0.00	0.00	0.00	2.32	0.00	0.00	0.00	0.00	2.32
73.5											
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
104.											
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
147.											
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
208.											
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
.487	.672	1.07	.981	1.82	2.48	5.74	10.1	20.6	32.8	1.19	100.0

variable z: PER CENT
variable x: PHASES
variable y: DIA(MIC)

9.99	20.0	30.0	40.0	50.0	60.0	70.0	80.0	90.0	100.0		
.220	.260	.478	.484	.483	.473	.245	.399	.525	.606	.707	4.84
3.25											
.113	.191	.217	.557	.646	.736	.234	.662E-01	.183	.515	.169	3.63
4.68											
.431E-01	.114	.256	.160	.698	1.45	1.31	.389	.418	.440	.438E-01	5.24
6.58											
.189	.234	.281	.889	.914	2.06	3.76	1.21	.684	.747	.193	11.2
9.19											
0.00	.139	.290	.364	1.35	1.18	4.01	4.94	1.48	1.13	.181	15.1
13.8											
0.00	0.00	0.00	.671	.884	.580	3.43	10.00	4.99	1.68	0.00	21.5
18.4											
0.00	0.00	0.00	0.00	.429	.774	8.10	7.57	6.41	.421	0.00	17.7
23.0											
0.00	0.00	0.00	0.00	0.00	0.00	1.80	4.76	6.79	0.00	0.00	12.6
36.8											
0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.03	2.62	2.84	0.00	6.29
52.0											
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
73.5											
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
104.											
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
147.											
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
208.											
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
.565	.938	1.52	3.10	4.78	7.86	16.1	32.1	24.0	8.29	1.29	100.0

Table 7. Summary of liberation characteristics of ilmenite

Type of grain or particle	C-127			C-157			Sumerse 30"
	+208μm	-203μm	Total	+208μm	-208μm	Total	
a) Ilmenite-hematite grains in ilmenite-hematite-silicate particles							
% of ilmenite-hematite grains occurring as:							
- free ilmenite-hematite grains	0.5	7.0	3.5	0.0	2.9	1.0	1.2
- more than 90% il-hem in particles (+90 %)	49.0	88.7	67.4	62.3	79.5	76.6	55.0
- more than 80% il-hem in in particles (+80 %)	82.4	94.4	87.9	73.5	88.3	79.9	75.5
- more than 70% il-hem in particles (+70 %)	88.6	96.6	92.3	74.5	90.8	84.3	85.7
- ave. vol % gangue in +70% particles	9.0	5.5	7.4	5.0	5.8	5.4	8.3
b) Ilmenite in ilmenite-hematite grains							
% of ilmenite occurring as:							
- more than 90% ilmenite (+90 %)	11.3	25.5	17.8	48.2	84.3	60.6	9.7
- more than 80% ilmenite (+80 %)	36.6	58.7	46.8	76.0	95.3	82.7	33.7
- more than 70% ilmenite (+70 %)	94.9	74.6	85.5	95.9	98.7	97.0	65.8
- more than 60% ilmenite (+60 %)	98.3	85.1	92.2	99.7	99.2	99.4	81.9
- ave. vol % hematite in +60% ilmenite-hem. grains	20.1	13.9	17.2	13.0	6.8	10.1	17.7

Table 8. Ilmenite-hematite grains

	C-127			C-157			Sumerse 30"
	+208μm	-208μm	Combined	+208μm	-208μm	Combined	
wt % free Fe oxides	2.9	1.8	2.8	tr	tr	tr	3.8
wt % hematite as ilmenite-hem. grains	2.8	12.6	5.1	3.2	3.6	3.3	16.0
wt % ilmenite as ilmenite-hem. grains	9.3	27.4	13.5	7.4	17.7	9.7	34.5
% ilmenite in ilmenite-hem. grains	77	67	73	70	83	75	68

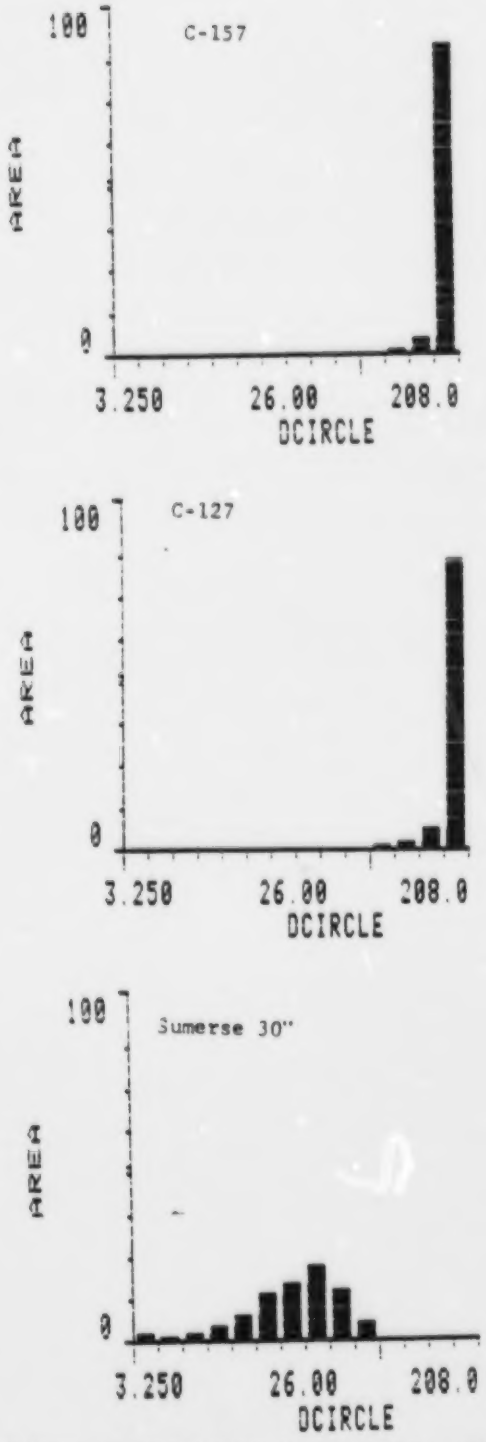


Fig. 1 Size distributions of particles in samples. The sizes along the base of the diagrams are -3.25, 3.25, 4.6, 6.5, 9.25, 13, 18.5, 26, 37, 52, 74, 104, 107, 208 and plus 208 μm.

Fig. 2A. BSE photograph showing silicate minerals (dark grey), rutile (med. grey), ilmenite-hematite grains (light grey), and zircon (white). Sample C-157

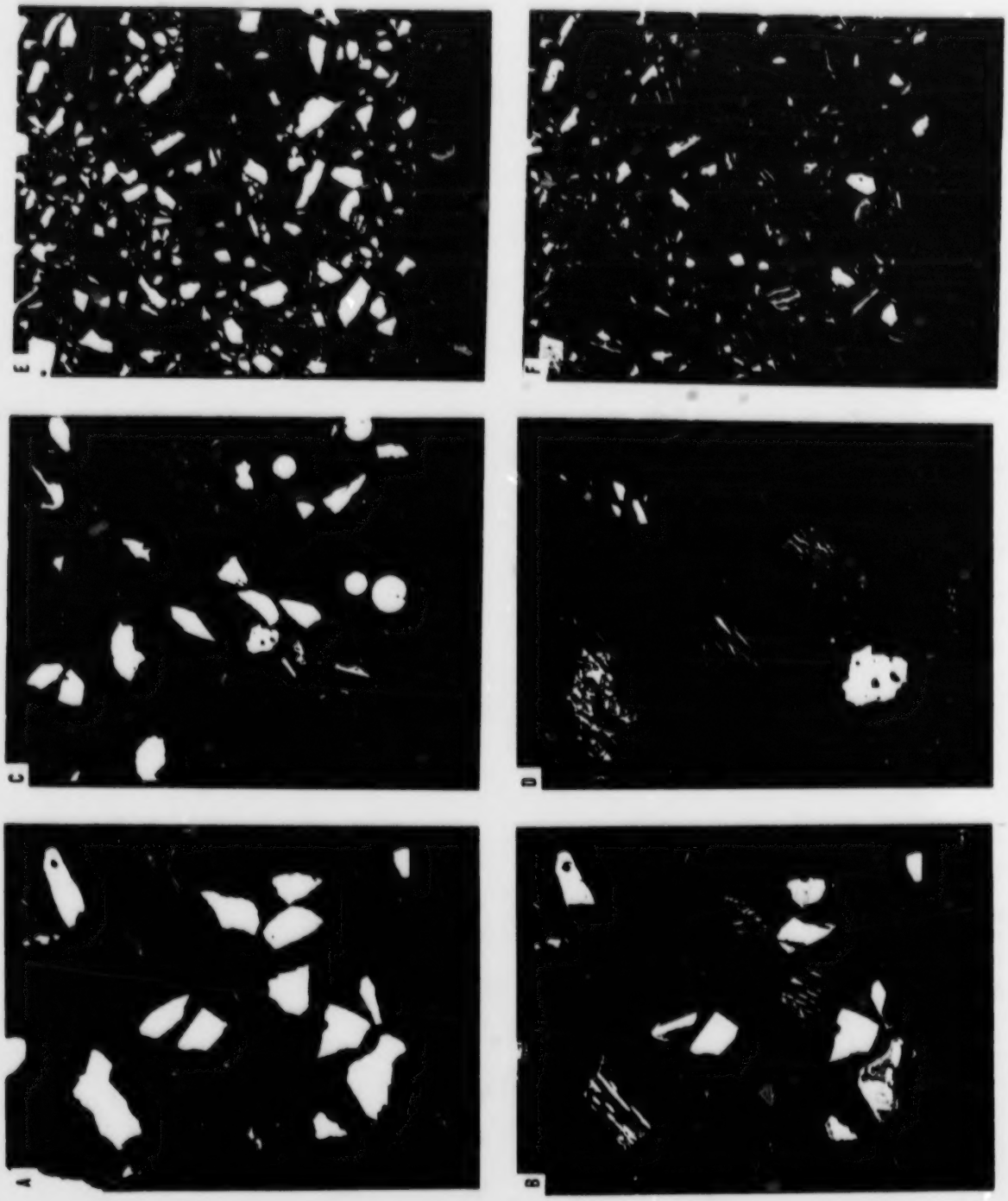
Fig. 2B. BSE photograph showing ilmenite-hematite grains. Ilmenite is medium grey, hematite lamellae are light grey and the white grain is zircon. The grain at the bottom left corner shows ilmenite partly replaced the by rutile. Sample C-157.

Fig. 2C. BSE photograph showing silicate minerals (grey) and ilmenite hematite grains (white). Sample C-127

Fig. 2D. BSE photograph showing ilmenite-hematite grains. The ilmenite is grey and hematite is white. Sample C-127.

Fig. 2E. BSE photograph showing silicate minerals (grey) and ilmenite-hematite grains (light grey and white). Sample Sumerse 30". Borders on the silicate minerals are artifacts.

Fig. 2F. BSE photograph showing ilmenite-hematite grains. The ilmenite is grey, and the hematite is white. Sample Sumerse 30".


E
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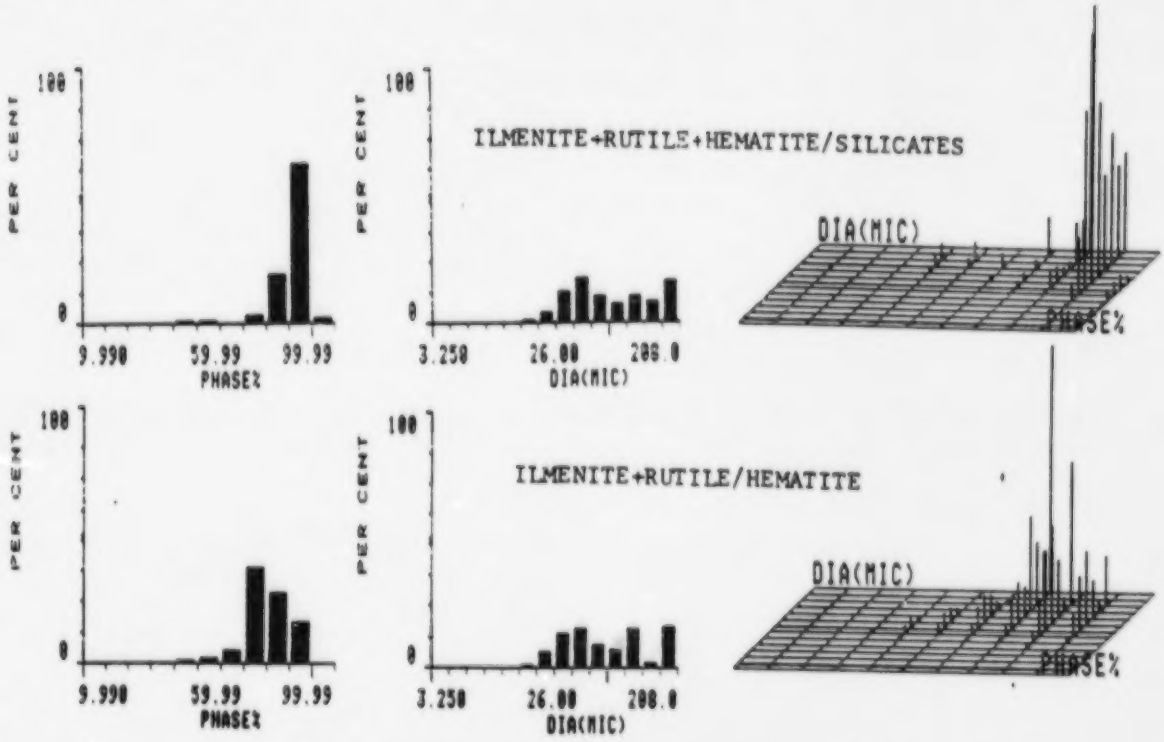

Fig. 3. Diagrams showing the liberation characteristics of the grains in sample C-127. The diagrams in the top row give the relationship of ilmenite-hematite grains to gangue minerals in particles, and the diagrams in the bottom row give the relationships of ilmenite plus rutile to hematite in ilmenite-hematite grains.

The top-left diagram shows the classification of particles containing ilmenite-hematite grains. The classification (phase %) is for particles containing 0-10 (9.99), 10-20, 20-30, 30-40, 40-50, 50-60 (59.99), 60-70, 70-80, 80-90, 90-99.99 (free) and 100 (free) vol % ilmenite-hematite grains. The heights of the bars represent the proportions of ilmenite-hematite in each class of particles. The bottom left diagram shows the classification of ilmenite plus rutile in ilmenite-hematite grains.

The top middle diagram shows the size distribution of ilmenite-hematite grains in the particles, and the bottom middle diagram shows the size distribution of ilmenite in the ilmenite-hematite grains. The size steps are -3.25, 3.25, 4.6, 6.5, 9.25, 13, 18.5, 26, 37, 52, 74, 104, 147, 208 and plus 208.

The 3D diagrams are combinations of the classifications and size distributions. The front of the diagrams corresponds to the classification with the extreme left line being for the 0-10 vol % class, and the extreme right for the 100 vol % class. The size is along the side of the diagram, with the -3.25 μm grains being along the front line, and the plus 208 μm grains along the back line.

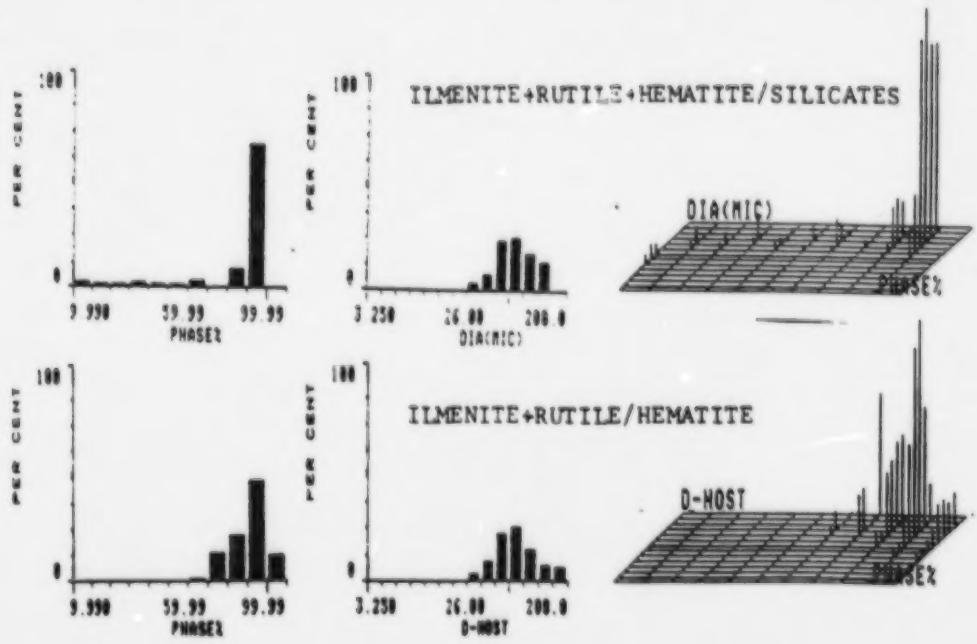

Fig. 4. Diagrams showing the liberation characteristics of the grains in sample C-157. The diagrams in the top row give the relationship of ilmenite-hematite grains to gangue minerals in particles, and the diagrams in the bottom row give the relationships of ilmenite plus rutile to hematite in ilmenite-hematite grains.

The top-left diagram shows the classification of particles containing ilmenite-hematite grains. The classification (phase %) is for particles containing 0-10 (9.99), 10-20, 20-30, 30-40, 40-50, 50-60 (59.99), 60-70, 70-80, 80-90, 90-99.99 (free) and 100 (free) vol % ilmenite-hematite grains. The heights of the bars represent the proportions of ilmenite-hematite in each class of particles. The bottom left diagram shows the classification of ilmenite plus rutile in ilmenite-hematite grains.

The top middle diagram shows the size distribution of ilmenite-hematite grains in the particles, and the bottom middle diagram shows the size distribution of ilmenite in the ilmenite-hematite grains. The size steps are -3.25, 3.25, 4.6, 6.5, 9.25, 13, 18.5, 26, 37, 52, 74, 104, 147, 208 and plus 208.

The 3D diagrams are combinations of the classifications and size distributions. The front of the diagrams corresponds to the classification with the extreme left line being for the 0-10 vol % class, and the extreme right for the 100 vol % class. The size is along the side of the diagram, with the -3.25 μm grains being along the front line, and the plus 208 μm grains along the back line.

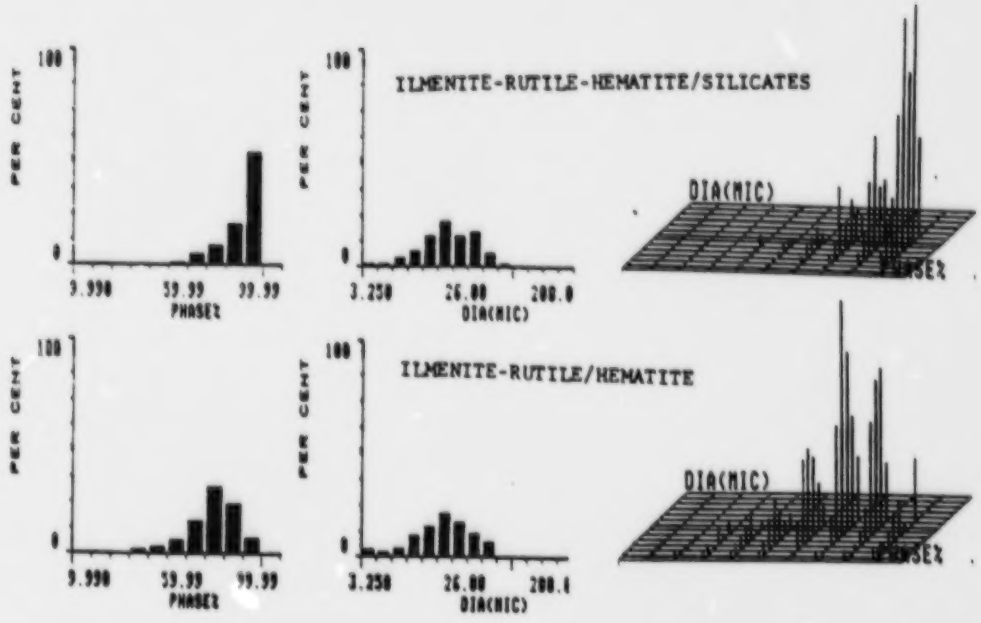

Fig. 5. Diagrams showing the liberation characteristics of the grains in sample Sumerse 30". The diagrams in the top row give the relationship of ilmenite-hematite grains to gangue minerals in particles, and the diagrams in the bottom row give the relationships of ilmenite plus rutile to hematite in ilmenite-hematite grains.

The top-left diagram shows the classification of particles containing ilmenite-hematite grains. The classification (phase %) is for particles containing 0-10 (9.99), 10-20, 20-30, 30-40, 40-50, 50-60 (59.99), 60-70, 70-80, 80-90, 90-99.99 (free) and 100 (free) vol % ilmenite-hematite grains. The heights of the bars represent the proportions of ilmenite-hematite in each class of particles. The bottom left diagram shows the classification of ilmenite plus rutile in ilmenite-hematite grains.

The top middle diagram shows the size distribution of ilmenite-hematite grains in the particles, and the bottom middle diagram shows the size distribution of ilmenite in the ilmenite-hematite grains. The size steps are -3.25, 3.25, 4.6, 6.5, 9.25, 13, 18.5, 26, 37, 52, 74, 104, 147, 208 and plus 208.

The 3D diagrams are combinations of the classifications and size distributions. The front of the diagrams corresponds to the classification with the extreme left line being for the 0-10 vol % class, and the extreme right for the 100 vol % class. The size is along the side of the diagram, with the -3.25 μm grains being along the front line, and the plus 208 μm grains along the back line.